EV223957427US

DP-309088
65899-0692

Mobile Satellite Radio Antenna System

Technical Field

[0001] The invention relates generally to radio antennas. More particularly, the invention relates to antenna reception of satellite and terrestrial re-transmitted satellite signals for mobile structures that include two or more antennas for mounting internally or externally on the mobile structure.

Background of the Invention

[0002] With reference to Figures 1 and 2, a number of antenna systems have been proposed which provide for the reception of satellite transmission signals, S (Figure 2), from a satellite 11, such as transmission signals for satellite digital audio radio service (SDARS), on mobile structures, such as an automotive vehicle, V. SDARS, for example, operates on the S-band frequencies ranging between 2320 -2345 MHz. Figure 1 illustrates a known after-market antenna system 1a that allows transfer of radio frequency (RF) energy across a dielectric, such as glass 3a, for reception of the satellite transmitted signals, S. The antenna system 1a provides for the transfer of RF energy through the glass 3a or other dielectric surfaces to avoid the undesirable procedure of having to drill holes, for example, through the windshield or window of a vehicle, V, for installation. Although adequate for most applications, after-market glass-mount antenna systems have been considered advantageous because they obviate the necessity of having to provide a proper seal around an installation hole or other window opening to protect the interior of the vehicle, V, and its occupants from exposure to external weather conditions.

[0003] In the known antenna system 1a depicted in Figure 1, RF signals from an antenna 2a are conducted across the glass surface 3a via a coupling device 4a that typically employs capacitive coupling, slot coupling or aperture coupling. The portion of the coupling device 4a on the interior of the vehicle, V, is connected to a matching circuit

5a which provides the RF signals to a low noise amplifier (LNA) 7a at the input of a receiver 8a via an RF or coaxial cable 6a.

[0004] Figure 2 illustrates an alternative embodiment of the antenna system 1a of Figure 1, except that antenna system 1b in Figure 2 includes an antenna 2b, which may range in height from approximately 35-80mm, that has been displaced to the roof of the vehicle, V, and is retained by a magnet or other securing means (not shown). Through cable 3b, the RF signal travels to the coupler 4b, which is mounted exteriorly on the vehicle's glass (e.g., back windshield), and to second coupler 4b, which is mounted on the glass, such that the second coupler 4b is positioned on the interior of the vehicle, V, in a directly opposing relationship to the first coupler 4b mounted on the exterior of the glass. The RF signal then travels through RF cable 5b to LNA 6b and then through RF cable 7b to receiver 8b. Known coupling devices that are similar to the coupler 4b may include other performance enhancements, such as an integrated receiver unit that minimizes cable runs so as to minimize coupler losses.

[0005] Both types of antenna mounting systems 1a, 1b illustrated in Figures 1 and 2 suffer from various deficiencies. First, the antennas 2a, 2b of Figures 1 and 2, respectively, is, in all likelihood, a second or even third antenna positioned on the vehicle (i.e. an additional antenna in view of the original equipment manufacture (OEM)-installed AM/FM antenna), and thus adds an unsightly appearance to the vehicle, V. Regarding the window mount antenna system 1a, RF coupling loss through the glass 3a is generally 1 dB or higher. This causes an increase in noise that results in degradation of receiver sensitivity. Even further, the couplers 4a may obstruct vehicle operator vision while also generally making the appearance of the vehicle, V, unsightly.

[0006] The vehicle body mount (i.e. roof mount) antenna system 1b includes other maintenance, safety, and performance issues. For example, the installation of antenna 2b is located remotely with respect to LNA 6b and radio receiver 8b, which is generally considered unattractive to consumers of mobile satellite services, such as SDARS. This

is true for several reasons. First, the roof mounted antenna 2b is unsightly, not only to the external observer, but also to the vehicle occupants where the RF cables 5b, 7b must be routed through the interior of the vehicle, V. Secondly, as a result of height restrictions on car carriers, truck carriers, or other vehicle carriers, an antenna 2b placed on the roof has to be below some maximum height, such that the overall vehicle height does not exceed the maximum allowable height whereby this causes a problem with being loaded on a carrier loaded on a carrier.

[0007] Thirdly, RF transmissions are often subject to multi-path fading. This is especially true of satellite transmitted signals, S. Signal blockages, or obstructed satellite signals, O (Figure 2), at the antenna can occur due to physical obstructions between a transmitter (e.g. the orbiting satellite 11) and the receiver (e.g. the antenna 2b on the vehicle, V), which undesirably results in service outages. For example, as illustrated in Figure 2, the physical obstructions that the antenna 2b typically encounters may be tall buildings, B, or trees, T, that impede line of sight (LOS) of the antenna 2b. In this scenario, SDARS service outages may occur when noise or multi-path signal reflections are sufficiently high with respect to the reception of the desired signal, S.

[0008] A need therefore exists for a vehicle antenna system that provides an effective means for reception of satellite transmitted signals while reducing maintenance issues and increasing signal performance. A need also exists for a vehicle antenna system that prevents additional holes from being drilled in a vehicle's exterior shell. Even further, a need also exists for a vehicle antenna system that eliminates the need to position a relatively large, unsightly antenna on the roof of a vehicle. Yet even further, a need also exists for a vehicle antenna system that eliminates the need to locate a magnetically mounted antenna on the roof or glass of a vehicle, or to use antenna couplers on the glass of a vehicle.

Summary of the Invention

[0009] The present invention relates to an antenna system for a vehicle. Accordingly, one embodiment of the invention is directed to an antenna system that includes at least one first and second antenna. The at least one first antenna is located about a first portion of a mobile structure and is capable of receiving satellite and terrestrial re-transmitted satellite signals. The at least one second antenna is located about a second portion of a mobile structure and is capable of receiving satellite and terrestrial re-transmitted satellite signals. The at least one first and second antenna receive the satellite and terrestrial re-transmitted satellite signals. Signal reception on the mobile structure is maintained by switching and/or combining the satellite and terrestrial re-transmitted satellite signals received by the at least one first and second antennas when the satellite and terrestrial re-transmitted satellite signals being received by the at least one first or second antenna is obstructed.

Brief Description of the Drawings

[0010] The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

[0011] Figure 1 illustrates a known antenna system that allows inductive transfer of RF energy across a dielectric such as glass for reception of satellite transmitted signals;

[0012] Figure 2 illustrates an alternative known embodiment of the antenna system of Fig. 1 mounted on a vehicle;

[0013] Figure 3 illustrates a vehicle including a vehicle antenna system for reception of satellite and terrestrial re-transmitted satellite signals according to an embodiment of the present invention;

[0014] Figures 4A-4E illustrates antennas that may be used in a combined multi-band terrestrial/satellite antenna according to the vehicle antenna system illustrated in Figure 3.

Description of the Preferred Embodiment

[0015] The above described disadvantages relating to Figures 1 and 2 are overcome and a number of advantages are realized by the antenna system, which is shown generally at 10 in Figure 3. As explained below, the antenna system 10 operates using two or more complementary antennas to cover the expected satellite signal, S, from one or more satellites 11 placed in synchronous or non-synchronous earth orbits. Satellite transmissions may be used for audio programming, but can be used for other purposes as well. Accordingly, the antenna system 10 is designed to increase the probability of uninterrupted reception of the signal, S, when physical obstructions, such as tall buildings, B, or trees, T, impede the LOS of at least one of the antennas, which results in an obstructed satellite signal, O. As illustrated, if the vehicle, V, includes at least one antenna positioned at the rear, R, where signal shadowing may occur (i.e. the signal, S, is obstructed), and at least one antenna positioned at the front, F, of the vehicle, V, where the signal, S, is seen by the antenna system 10. Thus, the fact that the signal, S, is received at the front, F, or because the signal, S, received at the front, F, is stronger than the obstructed signal, O, consistently uninterrupted operation of the antenna system 10 is more likely to be ensured.

[0016] Essentially, the antennas are strategically located in the vehicle, V, in a fashion such that the antennas are looking up toward the satellite 11. For example, in SDARS applications, the antenna typically looks up at the satellite 11 at a minimum angle of approximately 20^0 for satellite signal reception while seeking terrestrial re-transmitted satellite signals that are re-broadcast by a repeater at an angle approximately equal to 0^0. Accordingly, it is preferable to position the antenna relating to the antenna system 10 above the terrestrial transmission horizon such that any metallic obstructions on the vehicle, V, do not create signal loss.

[0017] As illustrated, the antenna system 10 comprises at least two or more antennas 12a, 12b, 14a, 14b, 16a, 16b, 18a, 18b mounted internally or externally on the surface of a mobile structure, such as a vehicle, V, for reception of satellite and terrestrial re-transmitted satellite signals, S. The antenna system 10 comprises at least two antennas, which may correlate to antenna pairs 12, 14, 16, and 18. Although the antennas 12a, 12b, 14a, 14b, 16a, 16b, 18a, 18b correlate to the antenna pairs 12, 14, 16, and 18, the antenna system 10 does not necessarily operate in pairs; it is contemplated that any desirable amount of antennas may be employed, such as, for example, two, three, four, five or more antennas to achieve the desired signal reception for maximized output performance.

[0018] As illustrated, each antenna pair 12, 14, 16, 18 is positioned in a generally symmetrical pattern at the front, F, or rear, R, about the vehicle, V, such that the antennas are mounted within or exteriorly on the vehicle, V. Although not required, it is preferable to locate the antennas at the opposing front, F, and rear, R, portions of the vehicle, V; however, a pair of complementary antennas may be located in a single housing or package (not shown) because the minimum distance the antennas may be separated by is at least one 1/4 wavelength, which may be a very nominal distance in view of higher SDARS-type frequencies. In particular, this applies to a terrestrial signal application such that two antennas of the same polarization may be spaced at least 1/4 wavelength apart, or two antennas of opposite polarization (i.e. vertically polarized and horizontally polarized antennas) may be placed in the same location. As illustrated, the antennas 12a, 14a, 16a, 18a, (i.e. "the antennas") are located at the front, F, of the vehicle, V, and the antennas 12b, 14b, 16b, 18b (i.e. "the b antennas") are located at a rear, R, of the vehicle, V. Even further, although the antennas pairs 12, 14, 16, 18 are shown to be positioned in a generally symmetrical pattern about the vehicle, V, the antennas 12a, 12b, 14a, 14b, 16a, 16b, 18a, 18b may be positioned at any desirable location on the vehicle, V, in any non-symmetric pattern, if desired.

[0019] Although the antennas 12a, 12b, 14a, 14b, 16a, 16b, 18a, 18b generally correlate to antenna pairs 12, 14, 16, 18, respectively, the antennas 12a, 12b, 14a, 14b, 16a, 16b, 18a, 18b do not necessarily operate exclusively within the designated antenna pair (e.g. antenna 12a does not necessarily operate exclusively with antenna 12b). In one embodiment of the invention, the antenna 12a, which is positioned on the exterior of windshield glass 20, may operate in concert with the antenna 14b, which is positioned within the vehicle, V, on the rear windshield glass 22. Another embodiment of the invention may include an antenna system 10 comprising an antenna configuration that includes any one of antennas 12a, 12b, 14a, or 14b positioned within (e.g. one of the antennas from antenna pair 14) or on the exterior (e.g. one of the antennas from antenna pair 12) of one of the glass portions 20, 22 that operates in concert with the antenna 16a positioned on the instrument panel 24 or antenna 16b positioned on the rear package shelf 26 within the vehicle. Another embodiment of the invention may be directed to an antenna system 10 that includes antenna 18a or 18b positioned on an exterior shell of the vehicle, such as an outer glass frame portion 28 or fender 30 with any one of the antennas 12a, 12b, 14a, 14b positioned on the interior or exterior of the glass 20, 22 or antennas 16a, 16b positioned on an instrument panel 24 or package shelf 26. Thus, it is contemplated that the antennas comprising the antenna system 10 may include at least two antennas that are located on any portion of the vehicle, V, such as the glass 20, 22, an instrument panel 24, rear package shelf 26, the exterior shell 28, 30, or any other desirable location such that the antennas are positioned exteriorly on the vehicle, V, or within the vehicle, V.

[0020] Once the antennas 12a, 12b, 14a, 14b, 16a, 16b, 18a, 18b are positioned, an SDARS-satellite cable and/or an SDARS-terrestrial cable, which is generally shown at 32a for the front, F, of the vehicle, V, and at 32b, for the rear, R, of the vehicle, V, extends toward a receiver 34 from the respective antennas 12a, 14a, 16a, 18a positioned at the front, F, and antennas 12b, 14b, 16b, 18b positioned at the rear, R. As explained

above, any desirable number of antennas 12a, 12b, 14a, 14b, 16a, 16b, 18a, 18b may be implemented in the vehicle in any desired configuration or pattern; therefore, for illustrative purposes, only one cable 32a is shown extending from the antenna 16a and one cable 32b is shown extending from the antenna 16b. However, it is contemplated that multiple cables 32a, 32b may be spliced or individually extend from multiple antennas positioned at the front, F, or rear, R, of the vehicle, V, for implementations including more than two antennas.

[0021] It is preferable to locate the receiver 34 as close to the antenna elements as possible such that losses in the cables 32a, 32b are kept to a minimum. In some implementations, it may not be possible to centrally locate the receiver 34 in the vehicle, V, such that both cables 32a, 32b have the same lengths and thus, the same losses. As illustrated, the receiver 34 is positioned about the rear, R, of the vehicle, V, such that the cable 32a is much longer than the cable 32b (i.e. the cable 32a has greater signal loss than the cable 32b). Essentially, in this embodiment of the invention, an LNA 104 (Figures 4A-4D) may be associated with the antennas located on the front, F, of the vehicle, V, and the antenna located on the rear, R, of the vehicle, V, may not include an LNA 104 due to the fact that the losses in the cable 32b are not substantial enough to warrant an amplification. Hence, it is possible to implement an antenna system that includes both passive and active antenna units.

[0022] The antennas 12a, 12b, 14a, 14b, 16a, 16b, 18a, 18b, which are hereinafter referred to as antennas 12a-18b, may be considered low-profile, multi-band terrestrial/satellite antennas. It is preferable that the antennas 12a-18b include a structure that minimizes the overall height (i.e. include a 'low-profile') of the antenna such that the antenna is essentially transparent to vehicle occupants and observers and not very noticeable. It is contemplated that 'low-profile' antennas may be defined to include any antenna height less than or equal to 20mm. Although it is preferable to minimize the height of the antennas 12a-18b, the antenna height may extend past what is considered to

be 'low profile,' as designated above, such that the antennas 12a-18b are positioned according to the antenna system 10, as explained above with respect to Figure 3.

[0023] Four possible embodiments of the multi-band terrestrial/satellite antennas 12a-18b that may be applied in the antenna system 10 are illustrated in Figures 4A-4D. The antennas 12a-18b implemented in the antenna system 10 may be a patch antenna 100a (Figure 4A), a loop antenna 100b (Figure 4B), a quadrifilar antenna 100c (Figure 4C), or a coupled-loop antenna 100d (Figure 4D). As illustrated, each antenna 100a-100d may be coupled to a structural element, such as a circuit board 102 or substrate 106, and an LNA 104. Each antenna 100a-100d may include a weatherproofing material (not shown) that may be applied to its exterior surface for protection against the deteriorating effects of rain, sunshine, etc. Additionally, a binding agent (not shown) may be applied to the interior surface of the antennas 100a-100d when fabricated into the final form as shown in Figures 4A-4D.

[0024] Referring specifically to Figure 4A, the patch antenna 100a may also include a ground plane 108 positioned under the substrate 106, and a conductive area 110 positioned over the substrate 106, which includes a feed point 112. The feed point 112 receives a pin (not shown) that extends through the LNA 104 for assembly and electrical communication purposes, which is subsequently soldered for directly connecting the antenna assembly. If any of the antennas 100a-100d are positioned on glass 20, 22, a conductive adhesive may be applied to a surface of the antenna 100a-100d to permit attachment thereto. Even further, if any of the antennas 100a-100d are secured to the instrument panel 24 or package shelf 26, the antenna 100a-100d may include a bezel, nut, and bolt, and LNA housing (not shown). Yet even further, if any of the antennas 100a-100d are secured to the outer glass frame portion 28 or fender 30, the antenna may also be secured via the bezel, nut, and bolt, and LNA housing combination about an OEM supplied passage for an AM/FM antenna (not shown).

[0025] Referring now to Figure 4B, the loop antenna 100b also includes a generally planar substrate 106 / ground plane 108, and a generally circular or oval conductive area 110. As illustrated, the circuit board 102, may act not only as a planar substrate 106, but also as a ground plane 108. Figures 4C and 4D illustrate alternative embodiments of the loop antenna 100b, such that the conductive element 110 is wrapped or disposed upon a generally tubular or cylindrical substrate 106 that is positioned over the ground plane 108. As seen in Figure 4C, the conductive element 110 is essentially a loop that is wrapped in a helical pattern about the cylindrical substrate 106. Alternatively, as seen in Figure 4D, the conductive element 110 comprises at least one loop portion with conductive strips that extend in a generally perpendicular pattern from the loop. According to the illustrated embodiments of the antennas in Figures 4B and 4C, the antennas 100b and 100c may be directly coupled to the LNA 104 via a soldering technique that includes a feed point at, on, or about the conductive element 110, as described above. Alternatively, the conductive elements 110 of the antenna 100d illustrated in Figure 4D are parasitic elements and are parasitically coupled with respect to the LNA 104.

[0026] It is known that antenna impedance is referenced from the ground; therefore, it is preferable to introduce the ground plane 108 in the design of the antennas 100a-100d to avoid undesirable ripple to obtain a smooth polar response. It is preferable to maintain a minimum ground plane 108 of approximately 100sq-mm or 100mm-diameter regardless of antenna position. If the antenna is located on the glass 20, 22, then ground plane 108 may be introduced without any structural alterations to the antenna; however, if the antenna is located on the front or rear dash 24, 26, the ground plane 108 is not effected because a ground plane already exists on the front or rear dash 24, 26. Referring to Figure 4A, the dielectric dimensions, dielectric constant, and dimensions of the conductive patch element 110 and the ground plane 108 determine the operating characteristics of the patch antenna 100a. According to one embodiment of the

invention, the patch antenna 100a may be defined to include an approximate surface area of 1 square inch and height of approximately 4mm to 6mm. The conductive patch element 110 may be approximately 0.5 square inches. Referring to Figure 4B, the loop or micro-strip antenna 100b may be etched on a low-loss dielectric. The loop antenna 100b operates in the TM21 mode and yields adequate performance for elevation angles approximately equal to 20 to 60 degrees and degraded performance at higher angles such as 70 to 90 degrees.

[0027] Referring now to Figure 4C, the diameter, height, and pitch angle of helical conductive elements 110 determine the operating characteristics of the quadrifilar antenna 100c. According to one embodiment of the invention, the quadrifilar antenna 100c may include a diameter approximately equal to 20mm and a height ranging from 6.0cm to 6.5cm. Referring now to Figure 4D, the ground plane 108, diameter, and length of the conductive elements 110 determine the operating characteristics of the coupled loop antenna 100d. According to one embodiment of the invention, the loop perimeter length may be approximately 1/2 wavelength and the height may be approximately equal to 30mm. Referring now to Figure 4E, an antenna according to another embodiment of the invention, which is seen generally at 100e, is a printed glass antenna. As illustrated, the printed glass antenna 100e comprises a conductive element 110 printed on an inner surface of the front, rear, or side glass 20, 22 of the vehicle, V, with a thin layer of film 106 disposed over the conductive element 110 on the inner portion 21 of the glass 20, 22. The LNA 104 is attached to the opposing side of the film layer 106.

[0028] Although not illustrated, it is contemplated that any desired antenna may be implemented in the design of the antenna system 10. For example, the antennas 12a-18b may include a patch antenna incorporating a plurality of micro-strips that have a specific impedance when placed on the glass, which is similar to the printed glass antenna illustrated in Figure 4E, except for the fact that that the micro-strip patch antenna is pre-tuned by the manufacturer prior to being located on the glass. Another alternative

antenna that may be applied to the antenna system 10 may be a cross-dipole antenna to receive terrestrial signals that include AM/FM and SDARS signals. Essentially, the cross-dipole antenna may comprise two circuit boards each including a dipole that are crossed at a 90^0 angle. Feed points of the circuit boards may be varied in any desirable polarization such as a horizontal, vertical, left-hand, right-hand polarization, by varying tapping points 90^0, 180^0, or 270^0.

[0029] As explained above, the antenna system enhances performance of the receiver by using at least a second antenna when a satellite signal is obstructed. Accordingly, there is a higher probability that the second antenna is not being obstructed, and therefore, the receiver would still be able to see the signal. Essentially, signal reception is maintained by switching and/or combining the satellite and terrestrial re-transmitted satellite signals received by the antennas. The switching and/or combining is determined by design-specific criteria used by the receiver, such as bit error rate, carrier to noise, or signal strength, or any other decision-based criteria algorithms. By introducing the second antenna, not only is performance improved, but other packaging, installation, and maintenance issues are overcome as well by locating discrete patch or loop-type antenna inside of, outside of, or about the vehicle. For example, because the antenna may be a low profile antenna, height restrictions on car carriers, truck carriers, or other vehicle carriers should not be an issue. Although discussion of the antenna system has focused on the particular application of a vehicle, V, it should be readily apparent to one skilled in the art, that the antenna system can be just as easily used in an aircraft, boat, train, mobile home, recreational vehicle or truck.

[0030] The present invention has been described with reference to certain exemplary embodiments thereof. However, it will be readily apparent to those skilled in the art that it is possible to embody the invention in specific forms other than those of the exemplary embodiments described above. This may be done without departing from the spirit of the invention. The exemplary embodiments are merely illustrative and should not be

considered restrictive in any way. The scope of the invention is defined by the appended claims and their equivalents, rather than by the preceding description.